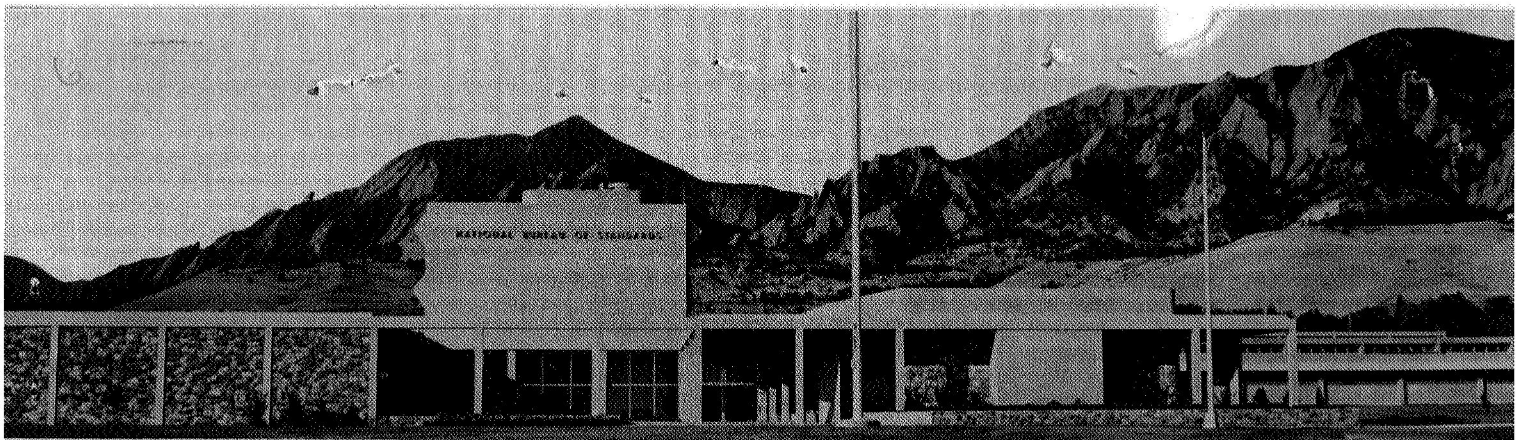

NBS REPORT

9711

COMPUTER PROGRAMS FOR SATURATION PROPERTIES OF HYDROGEN

SUPPLEMENT TO NBS REPORT 9288

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
BOULDER LABORATORIES
Boulder, Colorado

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[2] Located at Boulder, Colorado 80302.
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COMPUTER PROGRAMS FOR SATURATION PROPERTIES OF HYDROGEN

SUPPLEMENT TO NBS REPORT 9288

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Technical Report to
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Supplement to NBS Report 9288

June 25, 1968

COMPUTER PROGRAMS FOR SATURATION PROPERTIES OF HYDROGEN

by

R. D. McCarty

The pressure, temperature and enthalpy of saturated liquid and vapor parahydrogen are presented in the form of two computer programs. With these two routines and those in NBS Report 9288, "Computer Programs for Thermodynamic and Transport Properties of Hydrogen," August 18, 1967, it is possible to obtain values of the saturated liquid and the saturated vapor for all of the properties given in NBS Report 9288 (density, entropy, thermal conductivity, viscosity, specific heat and sound velocity).

Key words: Computer program, density, entropy, hydrogen, pressure, saturation, sound velocity, specific heat, temperature, thermal conductivity.

1.0 INTRODUCTION

Since the issuance of NBS Report 9288 it has become apparent from user reaction that in many applications it is necessary to obtain saturation values of the property in question. The purpose of this supplement is to provide the mechanism by which these values may be obtained in the most accurate and convenient manner.

2.0 TWO-PHASE REGION

The input variables to the property codes in NBS Report 9288 (hereafter referred to as the 9288 codes) are either pressure and temperature or pressure and enthalpy. In the case of the P-T input,

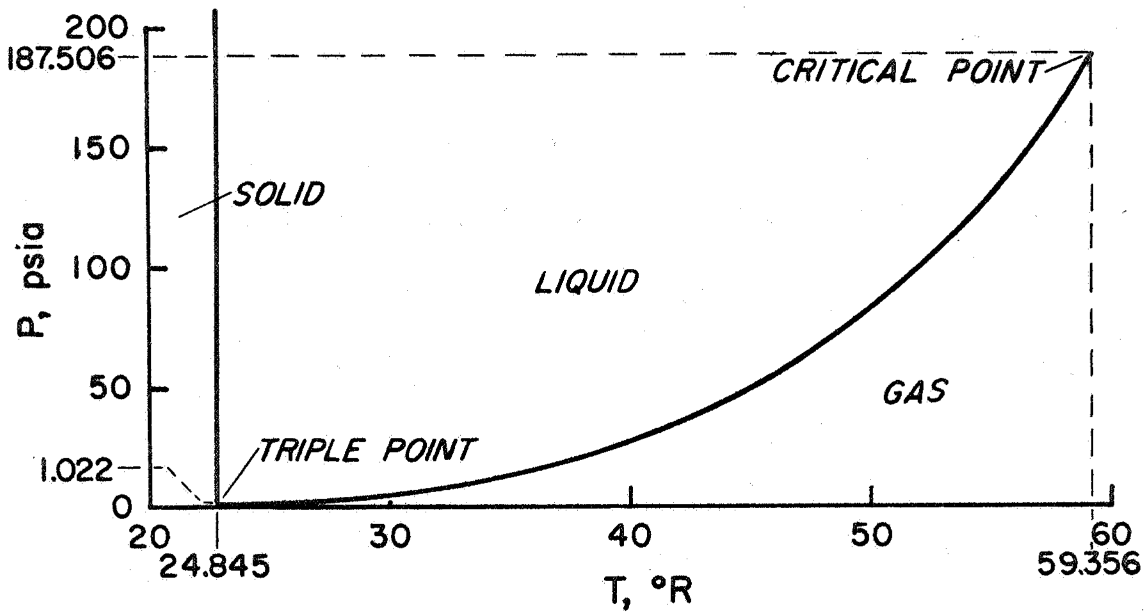

Figure 1. P-T Phase Diagram for Parahydrogen

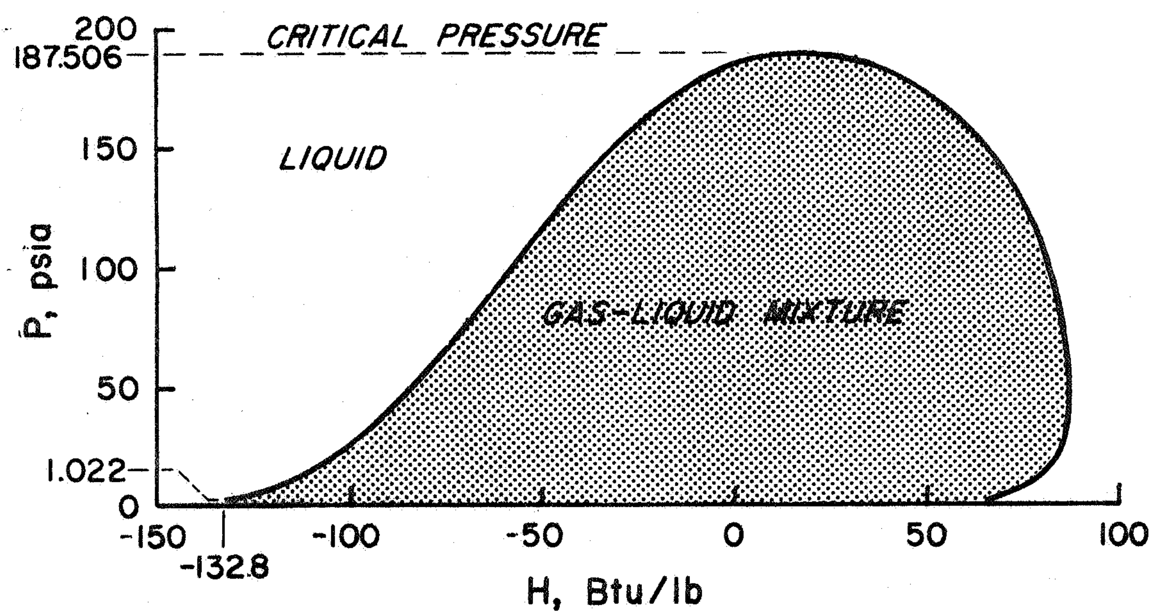

Figure 2. P-H Phase Diagram for Parahydrogen

the phase diagram in figure 1 shows the liquid-vapor coexistence region and the solid-liquid coexistence region as lines, which makes it impossible to pick a P-T input which will place the coordinates inside a two-phase region. However, this is not the case for the P-H input. All of the P-H points inside the shaded area in figure 2 are in the region of liquid-vapor coexistence. The solid-liquid coexistence region is not shown because of the special handling of this region by the 9288 codes. (See page 5 of the NBS Report 9288.) When any of the 9288 codes are entered with a P-H pair from the shaded area in figure 2, a value of the property in question is returned according to the discussion on pages 5 - 7 of NBS Report 9288, and also the users note dated 22 March 1968. <u>There is no built-in warning in any of the 9288 codes telling the user that he is in the liquid-vapor two-phase region. This means the user has to be aware of what conditions he is trying to process</u>. In applications where it is important to know when a particular P-H call is in the two-phase region, a call, T = PHTEMP(P,H,Q), is suggested. The value of Q that is returned has to be checked, and if Q is $0 < Q < 1$ then the P-H input is in the liquid-vapor coexistence region. Q is the quality, defined as the percent (by mass) of the vapor phase present. See page 8 of NBS Report 9288 for definitions of Q in other regions.

3.0 PROGRAMS

The two function programs PSATH(P,HG,HL) and TSATH(T,HG,HL) allow either a temperature or pressure input. The first letter of each function is the input variable which is repeated as the first argument. The other two arguments are output arguments and are the enthalpy of the saturated vapor and the enthalpy of the saturated liquid, respectively. The value of the function returned is either the pressure of the saturated liquid or the temperature of the saturated liquid depending upon which was an input variable, i.e., PSATH(P,HG,HL) returns the temperature of the saturated liquid for an input pressure, and TSATH(T,HG,HL) returns the pressure of the saturated liquid for an input temperature.

TABLE 1. Calling sequences

Property wanted	Input	Calls to make
Enthalpy of saturated liquid (HL)	T	P = T SAT H (T,HG,HL)
Enthalpy of saturated liquid (HL)	P	T = P SAT H (P,HG,HL)
Enthalpy of saturated vapor (HG)	T	P = T SAT H (T,HG,HL)
Enthalpy of saturated vapor (HG)	P	T = P SAT H (P,HG,HL)
Entropy of saturated liquid (SL)	T	P = T SAT H (T,HG,HL); SL = PHENTR(P,HL)
Entropy of saturated liquid (SL)	P	T = P SAT H (P,HG,HL); SL = PHENTR(P,HL)
Entropy of saturated vapor (SG)	T	P = T SAT H (T,HG,HL); SG = PHENTR(P,HG)
Entropy of saturated vapor (SG)	P	T = P SAT H (P,HG,HL); SG = PHENTR(P,HG)
Now substitute all other properties here	Input either P or T	Call T SAT H for T input Call P SAT H for P input Call PH property code here with appropriate input

BE SURE TO USE THE PH INPUT CODES

If either program is entered with a value outside the pressure or temperature range of the saturation curve, the variable is set to the nearest end point of the curve. Figure 2 shows end points of P-T saturation curve. Each program occupies 236 octal locations.

4.0 TWO-PHASE PROPERTIES

To obtain either the value of a property for the saturated liquid or the saturated vapor, the scheme in table 1 should be followed. Briefly, this means if you want the enthalpy of a phase boundary, a single call will suffice. If you want the value of another property, you must first find the corresponding enthalpy and then make a second call to find the value of the property you want. The P-H input 9288 codes should always be used to obtain saturation values. The P-T input codes will give answers in either the liquid or the vapor regions close to the saturation curve, but in many instances they will not be as accurate as values obtained from a P-H call, and there is no way of predicting which side of the boundary (liquid or vapor) will be returned.

4.1 Errors

The deviation plots in Report 9288 are applicable to the properties obtained in the manner outlined here.

4.2 Data

The sources of data for the interpolation grids are reported in NBS Report 9288. In the case of saturation values for the transport properties, i.e., viscosity, thermal conductivity, and specific heats, the returned values should be considered to be the value of the property as the saturation boundary is approached from the single-phase side.

APPENDIX 1.

PROGRAM LISTINGS CDC 3600

```
      FUNCTION TSATH(TEMP,HG,HL)
      DIMENSION R(19),TL(19),TG(19),TF(19)
      DATA(R=1.022,2.0,4.0,8.0,14.0,25.0,43.0,69.0,99.0,128.0,151.0,
     1165.,176.0,182.0,185.0,186.5,187.25,187.46875,187.506),(TF=24.845,
     227.07,29.81,33.07,36.18,39.96,44.12,48.33,51.97,54.79,56.72,57.80,
     358.57,58.99,59.18,59.29,59.34,59.353,59.356),(TG=60.31,65.11,70.59
     4,76.35,80.98,85.11,87.40,86.54,81.94,74.15,64.83,56.86,47.34,39.56
     5,33.46,28.34,22.31,18.66,16.55),(TL=-132.8,-129.13,-124.25,-117.79
     6,-110.86,-101.3,-89.04,-74.52,-58.58,-43.43,-30.07,-20.56,-11.13,
     7-4.27,1.17,5.54,10.83,14.29,16.36)
      T=TEMP
      IF(T.LT.24.845)T=24.845
      IF(T.GE.59.356)T=59.356
      DO 104 I=2,19
      IF(T-TF(I))102,101,104
  101 HL=TL(I)
      HG=TG(I)
      TSATH=R(I)
      RETURN
  102 D=TF(I)-TF(I-1)
      TRR=TF(I)-T
      TTR=T-TF(I-1)
      HL=(TL(I)*TTR+TL(I-1)*TRR)/D
      HG=(TG(I)*TTR+TG(I-1)*TRR)/D
      TSATH=(R  (I)*TTR+R  (I-1)*TRR)/D
      RETURN
  104 CONTINUE
      RETURN
      END
```

```
      FUNCTION PSATH(PRESS,HG,HL)
      DIMENSION R(19),TL(19),TG(19),TF(19)
      DATA(R=1.022,2.6,4.0,8.0,14.0,25.0,43.0,69.0,99.0,128.0,151.0,
     1165.,176.0,182.0,185.0,186.5,187.25,187.46875,187.506),(TF=24.845,
     227.07,29.81,33.07,36.18,39.96,44.12,48.33,51.97,54.79,56.72,57.80,
     358.57,58.99,59.18,59.29,59.34,59.353,59.356),(TG=60.31,65.17,70.59
     4,76.35,80.98,85.11,87.40,86.54,81.94,74.15,64.83,56.86,47.34,39.56
     5,33.46,28.34,22.31,18.66,16.55),(TL=-132.8,-129.13,-124.25,-117.79
     6,-110.86,-101.3,-80.04,-74.52,-58.58,-43.43,-30.07,-20.56,-11.13,
     7-4.27,1.17,5.54,10.83,14.29,16.36)
      P=PRESS
      IF(P.LT.1.022)P=1.022
      IF(P.GE.187.506)P=187.506
      DO 104 I=2,19
      IF(P-R(I))102,101,104
  101 HL=TL(I)
      HG=TG(I)
      PSATH =TF(I)
      RETURN
  102 D=R(I)-R(I-1)
      PRR=R(I)-P
      PPR=P-R(I-1)
      HL=(TL(I)*PPR+TL(I-1)*PRR)/D
      HG=(TG(I)*PPR+TG(I-1)*PRR)/D
      PSATH =(TF(I)*PPR+TF(I-1)*PRR)/D
      RETURN
  104 CONTINUE
      RETURN
      END
```

APPENDIX 2.

PROGRAM LISTINGS IBM

```
      FUNCTION TSATH(TEMP,HG,HL)
      DIMENSION R(19),TL(19),TG(19),TF(19)
      DATA R/1.022,2.0,4.0,8.0,14.0,25.0,43.0,69.0,99.0,128.0,151.0,
     1165.,176.0,182.0,185.0,186.5,187.25,187.46875,187.506/
      DATA                                                      TF/24.845,
     227.07,29.81,33.07,36.18,39.96,44.12,48.33,51.97,54.79,56.72,57.80,
     358.57,58.99,59.18,59.29,59.34,59.353,59.356/
      DATA                                             TG/60.31,65.11,70.59
     4,76.35,80.98,85.11,87.40,86.54,81.94,74.15,64.83,56.86,47.34,39.56
     5,33.46,28.34,22.31,18.66,16.55/
      DATA                                TL/-132.8,-129.13,-124.25,-117.79
     6,-110.86,-101.3,-89.04,-74.22,-58.58,-43.43,-30.07,-20.56,-11.13,
     7-4.27,1.17,5.54,10.83,14.29,16.36/
      T=TEMP
      IF(T.LT.24.845)T=24.845
      IF(T.GE.59.356)T=59.356
      DO 104 I=2,19
      IF(T-TF(I))102,101,104
  101 HL=TL(I)
      HG=TG(I)
      TSATH=R(I)
      RETURN
  102 D=TF(I)-TF(I-1)
      TRR=TF(I)-T
      TTR=T-TF(I-1)
      HL=(TL(I)*TTR+TL(I-1)*TRR)/D
      HG=(TG(I)*TTR+TG(I-1)*TRR)/D
      TSATH=(R (I)*TTR+R (I-1)*TRR)/D
      RETURN
  104 CONTINUE
      RETURN
      END
```

```
      FUNCTION PSATH(PRESS,HG,HL)
      DIMENSION R(19),TL(19),TG(19),TF(19)
      DATA R/1.022,2.0,4.0,8.0,14.0,25.0,43.0,69.0,99.0,128.0,151.0,
     1165.,176.0,182.0,185.0,186.5,187.25,187.46875,187.506/
      DATA                                                    TF/24.845,
     227.07,29.81,33.07,36.18,39.96,44.12,48.33,51.97,54.79,56.72,57.80,
     358.57,58.99,59.18,59.29,59.34,59.353,59.356/
      DATA                                          TG/60.31,65.11,70.59
     4,76.35,80.98,85.11,87.40,86.54,81.94,74.15,64.83,56.86,47.34,39.56
     5,33.46,28.34,22.31,18.66,16.55/
      DATA                           TL/-132.8,-129.13,-124.25,-117.79
     6,-110.86,-101.3,-89.04,-74.22,-58.58,-43.43,-30.07,-20.56,-11.13,
     7-4.27,1.17,5.54,10.83,14.29,16.36/
      P=PRESS
      IF(P.LT.1.022)P=1.022
      IF(P.GE.187.506)P=187.506
      DO 104 I=2,19
      IF(P-R(I))102,101,104
  101 HL=TL(I)
      HG=TG(I)
      PSATH =TF(I)
      RETURN
  102 D=R(I)-R(I-1)
      PRR=R(I)-P
      PPR=P-R(I-1)
      HL=(TL(I)*PPR+TL(I-1)*PRR)/D
      HG=(TG(I)*PPR+TG(I-1)*PRR)/D
      PSATH =(TF(I)*PPR+TF(I-1)*PRR)/D
      RETURN
  104 CONTINUE
      RETURN
      END
```